A STUDY OF SOME PHYSICAL-CHEMICAL FACTORS AFFECTING SHRINKAGE OF ICE CREAM

BY

JOHN JOSEPH SHEURING

B.S., University of Illinois, 1940
M.S., University of Illinois, 1942

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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A STUDY OF SOME PHYSICAL-CHEMICAL FACTORS AFFECTING SHRINKAGE OF ICE CREAM

During the past twenty years one of the chief aims of the ice cream industry has been to produce a frozen product smooth in texture. Simultaneously, one of the major problems that arose was shrinkage of ice cream in the container. This shrinkage problem has become increasingly more troublesome, and today it is one of the most important unsolved technical problems in the ice cream industry.

The shrinkage problem is by no means a simple one since the susceptibility of ice cream to shrinkage cannot be predicted by any known condition or test. Moreover, little is known as to the fundamental causes of shrinkage.

The term shrinkage as used herein is meant the loss of volume which occurs in ice cream before any part of the product has been removed from the container. Shrinkage as related to ice cream is not a relatively new term, yet the literature contains little information regarding this defect.

Tracy (29), in 1924, was the first researcher to publicly recognize shrinkage of ice cream. He reported that certain "improvers" in ice cream might result in shrinkage development. His work was later verified by Isenberg and Bear (20).

Cole (7), in 1940, originated a method of inducing artificial shrinkage of ice cream by submitting it to a vacuum treatment. Modifications of his method have been used by most of the recent investigators.

Tracy, Hoskisson, and Weinreich (30), in 1941, published the results of a comprehensive study of some factors that affected shrinkage of ice cream and advanced theories as to how the various conditions caused the defect. They believed that conditions which prevent viscous flow and add to the solid phase and structure of ice cream prevent shrinkage. Those conditions are low storage temperatures, large ice crystals,

fat clumping, use of superheated condensed milk, precipitated casein, and large air cells.

Dahle *et al.* (9, 10, 11, 12, 17, 23) have published several articles dealing with the shrinkage problem. Although their findings frequently conflicted with some of the results reported by other investigators, they believed that shrinkage is fundamentally a problem of protein stability of the mixes. They also stressed the importance of the bond which exists between the container wall and ice cream as a factor in shrinkage development of ice cream.

Conflicting results have been reported in the literature concerning the importance of the factors of mix acidities (17, 30, 31), increasing amounts and various sources of milk fat, milk solids-not-fat, sweetening agents, and stabilizers upon the shrinkage problem (11, 12, 17, 22, 23, 24, 27, 30, 33). Likewise, there is considerable disagreement regarding the importance of dry ice, container linings, types of storage cartons, and the effect of protein stability upon shrinkage of ice cream (3, 7, 12, 15, 17, 20, 22, 23, 27, 30, 33).

Although some investigators (11, 12, 17, 26, 27) believed that the surface tension of the mixes might be an important factor in shrinkage of ice cream, only Tarassuk and Hutton (27) presented limited data to substantiate their beliefs.

Kobler (21), in 1908, was one of the first workers to study the surface tension of milk. He showed that the surface tension of milk from inflammed udders, in some cases, differed from normal milk. He reported that when milk sours, the surface tension increases at first and later decreases. He explained this phenomenon on the basis that the bacteria which caused souring also liberated lower fatty acids which reduced the surface tension of the milk.

Other investigators (1, 2, 5, 8) have found that aging and heating of milk affect the surface tension. The effect of milk fat upon the surface tension of milk has been reported by several investigators (2, 5, 8, 13, 16, 21) with the general

belief that milk fat tends to lower surface tension. Practically nothing is known concerning the effect of fatty acids, surface-active agents, and the major components of mixes upon their surface tension, however Tarassuk, *et al.* (28) reported that rancidity caused a reduction in surface tension of milk. They believed the reduction in surface tension was undoubtedly due to the action of free fatty acids.

GENERAL PROCEDURE

Ice cream is an extremely complex physical and chemical system that is easily altered by slight variations in processing, freezing, and storage procedures. Likewise, only slight variations in temperature will alter the physical characteristics of ice cream. If results are expected to be reliable and significant in a study involving such a complex system as ice cream, standard procedures and experimental methods must be rigidly followed throughout the investigation.

The following general procedures were followed in this investigation: (a) all mixes were made from fresh cream, plain condensed skimmilk, sugar, and stabilizer unless otherwise specified; (b) all pasteurizing, homogenizing, freezing, and storage conditions were standardized; and (c) shrinkage was artificially induced by the application of 20 pounds per square inch of air pressure for 30 minutes at — 15° F.

Mixes were tested for titratable acidity (32) ; pH, using a Beckman Model M potentiometer; per cent of fat and total solids (19) ; protein stability, using a modification of the method described by Doan (13) ; specific gravity, using a Westphal balance; viscosity, using a Hoeppler viscosimeter (18) ; microscopical examination of the size and number of fat globules; and surface tension, using the method described by Du Nouy (14).

Ice cream samples were tested for air cell size using a modification of the method described by Blanton (4) ; and shrinkage was measured, using ice water to fill the voids in the ice cream containers.

EXPERIMENTAL

The experimental phase of the study was divided into three parts: (a) preliminary experiments, (b) methods of inducing shrinkage, and (c) effect of surface tension of mixes upon shrinkage of ice cream.

Preliminary Experiments

Effect of homogenization pressures.

Varying the mix homogenization pressures from the normal ranges of 2500 to 3000 pounds per square inch did not significantly affect shrinkage of the ice cream. Ice cream that was made from homogenized mixes developed slightly more shrinkage than similar samples made unhomogenized mixes.

Effect of types of storage containers.

Ice cream samples that contained 80, 100, and 120 per cent overrun were stored in paper cartons, unsealed tin cans, and sealed tin cans. Samples of the ice cream were subjected to both the vacuum and pressure methods of inducing shrinkage. Ice cream that was in the paper containers always shrank more than comparable samples stored in unsealed tin cans. Ice cream stored in sealed tin cans did not shrink.

Effect of applied external pressures.

Ice cream samples containing 80, 100, and 120 per cent overrun were stored in paper cartons, sealed and unsealed tin cans. All samples were subjected to increasing amounts of air pressure (2, 4, 8, 10, 12, and 15 pounds per square inch) for 30 minutes at $-15°$ F. Ice cream samples in the sealed tin cans did not shrink. The amount of shrinkage that developed in the other containers was proportional to the amount of air pressure that was applied.

Effect of various commercial stabilizers.

Ten different stabilizer and stabilizer-emulsifier combina-

tions were added to mixes made from the same milk and sugar ingredients. The ice cream samples were subjected to 20 pounds of air pressure for 30 minutes. Considerable differences in the amounts of shrinkage that developed were observed which indicated that stablizers are an important factor in the shrinkage problem.

Methods of Inducing Shrinkage

If reliable data are to be obtained in a study of this type then methods of inducing shrinkage in ice cream must be used that will give results that can be duplicated.

Four series of 25 samples of ice cream each were subjected to the following methods of inducing shrinkage: (a) a vacuum of 25 inches of mercury for 30 minutes at — 15° F. was applied to series 1; (b) air pressure of 20 pounds per square inch was applied to series 2 for a period of 30 minutes at — 15° F.; (c) samples in series 3 were subjected to continuous shaking for 30 minutes at — 15° F.; and (d) samples in series 4 developed natural shrinkage during storage for 6 months in an ice cream cabinet at — 5° F. ± 2° F.

An analysis of the data showed the following: (a) inducing shrinkage in ice cream by mechanical shaking at constant temperatures results in practically no shrinkage. (b) the pressure method of inducing shrinkage gives results that are more reliably duplicated than the other methods used in this study; and (c) three samples of ice cream should be submitted to the pressure treatment in order to secure statistically significant results. No definite correlations were obtained that indicated any of the methods tried would induce shrinkage that compared significantly with the natural defect.

Effect of Surface Tension

Effect of milk fat.

Two series of mixes were prepared. In one series the percentage of milk fat was increased while the percentages of

the other mix solids remained constant. In the other series, the concentration of milk fat in the water portion of the mixes varied but the concentration in water of the other mix components remained constant. Increased concentrations of milk fat lowers the pH, protein stability, and surface tension of mixes but increases mix viscosity. Increasing the amount of milk fat in mixes favors the development of shrinkage of ice cream.

Effect of milk solids-not-fat.

Two series of mixes were prepared. In one series the percentage of milk solids-not-fat was increased while the percentages of the other mix solids remained constant. In the other series, the concentration of milk solids-not-fat in the water portion of the mixes varied but the concentration in water of the other mix components remained constant. Increasing the concentrations of milk solids-not-fat tends to lower the pH, protein stability, and surface tension of mixes but increases mix viscosity.

Effect of sweetening agents.

Increasing the amounts and the concentrations in water of Frodex*, sucrose, corn sirup, Sweetose**, and dextrose decreased the surface tension and slightly lowered the pH of mixes. The type of sugar was more influential than the amounts that were used in reducing the surface tension and affecting shrinkage development of ice cream. Ice cream containing dextrose shrank most followed in order by ice creams containing Sweetose, corn sirup, sucrose, and Frodex.

Effect of stabilizers.

Mixes containing sodium alginate had lower surface tensions than comparable mixes that contained gelatin or sodium

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* dried corn sirup solids

** enzyme converted corn sirup

carboxymethylcellulose. The type of stabilizer was more important than the amounts that were used in affecting the surface tension of mixes and influencing shrinkage of ice cream.

Effect of emulsifiers.

Polyoxethylene sorbitan trioleate, lecithin, sorbitan monolaurate, a polyethylene ether of a hydroxy fatty acid, glycerol monostearate, and diglycol laurate exerted surface active properties in mixes and lowered surface tension while favoring shrinkage development of ice cream.

Effect of fatty acids.

Oleic acid decreased the surface tension of mixes to a greater extent than did butryic, palmitic, and stearic acids and also favored greater shrinkage of ice cream. Ice cream that was made from rancid cream and that made from rancid butter shrank more than comparable samples made from sweet cream and from sweet cream butter.

SUMMARY AND CONCLUSIONS

From the results obtained in this study, the following facts are evident: (a) although freezing and subsequent melting of ice cream frequently results in fat clumping and destabilization of the mix proteins, those factors could not be definitely correlated with shrinkage of ice cream; (b) a decrease in viscosity of the mix results after ice cream melts; (c) milk fat, milk solids-not-fat, sodium alginate, polyoxyethylene sorbitan trioleate, lecithin, sorbitan monolaurate, glycerol monostearate, diglycol laurate, dextrose, butryic, oleic, palmitic, and stearic acids lower the surface tension of mixes and increase the shrinkage susceptibility of ice cream; (d) sucrose, Frodex, gelatin, and sodium carboxymethylcellulose only slightly affect the surface tension of mixes and shrinkage of ice cream; (e) the correlations between the reduction in surface tension of mixes and increase in shrinkage of ice cream are significant in

most cases; (f) an increase in surface tension and decrease in protein stability of mixes resulted after freezing and subsequent melting; (g) homogenization of mixes is not an important factor in the shrinkage problem when normal procedures are used; (h) the type of storage container that is used for ice cream is an important factor in the shrinkage problem; (i) ice cream that was stored in sealed tin cans did not shrink when subjected to the various methods of producing artificial shrinkage nor after 15 months of storage at relatively constant temperatures; and (j) whether the milk ingredients come Jersey or Holstein cows, is not an important factor in the shrinkage problem.

It is illogical to say that any single chemical factor or physical condition is the complete cause of or the only process that is involved in shrinkage of ice cream. A large number of physical and chemical factors can be involved if the various conditions of temperature, pressure, processing procedures, freezing methods, and mix composition are varied.

On the basis of the results that have been reported by previous investigators and the data that have been presented in this thesis, the author believes it is logical to state that the factors studied which reduce the surface tension of mixes, are also important in the development of conditions in mixes and ice cream which favor shrinkage if all of the other physical and chemical factors of mix composition, processing procedures, freezing methods, and storage conditions remain constant.

Evidence has been submitted that verify the findings of Tracy *et al.* (30) concerning various factors that favor shrinkage development of ice cream. Data are presented which show that factors which decrease the surface tension of mixes are also the same factors that are usually associated with increased shrinkage of ice cream. Explanations have been given that show how the various factors possibly affect the surface tension of mixes and influence ice cream shrinkage.

Various theories have been advanced by previous investigators (11, 12, 26, 30) concerning the processes involved in the

shrinkage problem. Explanations and data are presented that show on the basis of the results obtained concerning surface properties of mixes and ice cream that the theories are logical.

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VITA

The author, John Joseph Sheuring, was born in Champaign County, Illinois, January 17, 1910, and received his elementary and high school education in the public schools of that county.

He attended the Eastern Illinois State College, Charleston, Illinois from September, 1929 to June, 1931. From 1931 to 1937, he taught in the public schools of Champaign County and attended summer sessions at the Eastern Illinois State College, Illinois Normal University, and the University of Illinois. He entered the College of Agriculture, University of Illinois in September, 1937 and was graduated with High Honors, February, 1940.

In September, 1940, the author joined the Dairy Husbandry staff of the University of Illinois as a full-time assistant. He received his M. S. degree in Dairy Technology from the University of Illinois in July, 1942. He entered the United States Air Forces in July, 1942 and was discharged from the service as a Captain in March, 1946. He returned to the University of Illinois as an Instructor in Dairy Technology in 1946 and passed his preliminary examinations for the doctorate in May, 1948.

The author joined the University of Georgia Dairy Department staff as an Associate Professor of Dairying in August, 1948. He served as Acting Head of the Dairy Department during the winter quarter of 1949 and is now in charge of the University of Georgia

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The author is a member of the Gamma Sigma Delta and Sigma Xi honorary societies. He is a member of the American Dairy Science Association, Association of Southern Agricultural Workers, Dixie Institute of Food Technologists, and the American Association of University Professors.

Following is a partial list of his publications:

1. Sheuring, J. J., and Tuckey, S. L. A Study of the Changes Occurring in the Fat Constants of Milk fat of Cheddar Cheese During the Ripening Process. J. Dairy Sci., 30 (11) : 803-816. 1947

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The author was married to Cosette Lawwill, Danville, Illinois, June 15, 1934. They have twin nine year old sons, Robert and Bruce.